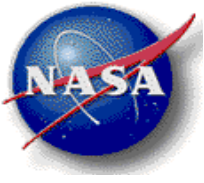


# Application of Terahertz Imaging and Backscatter Radiography to Space Shuttle Foam Inspection

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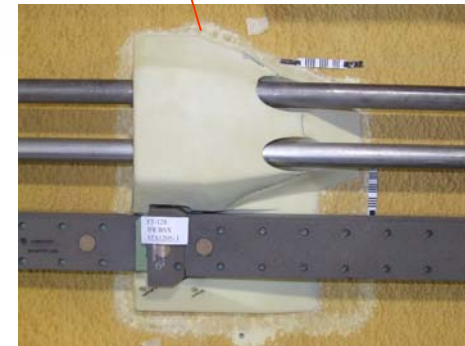
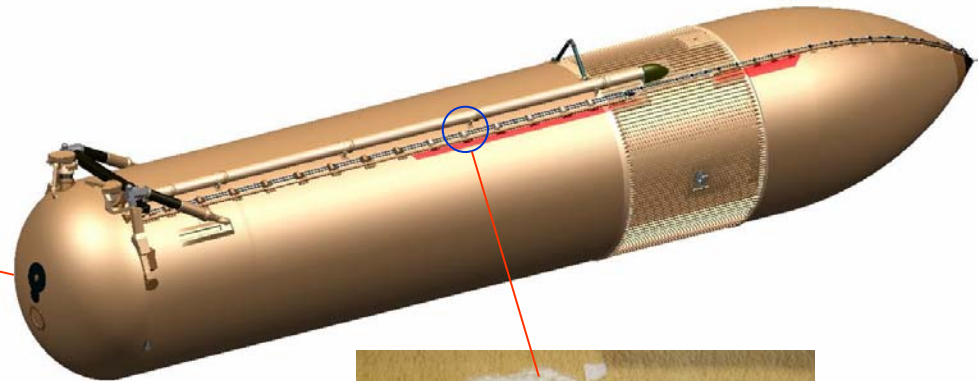


# Background

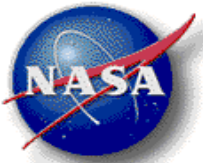


- **External Fuel Tank Background**

- ET holds cryogenic liquid hydrogen and oxygen fuel for shuttle main engines
- Polyurethane foam insulation prevents cryogenic fuel from boiling as well as ice formation
- Aero loads during launch can produce foam debris potentially damaging the shuttle orbiter
- After the Columbia accident, ET foam debris was identified as a likely cause of the orbiter wing damage
- NDE is performed on ET foam as one method of preventing critical foam debris during launch

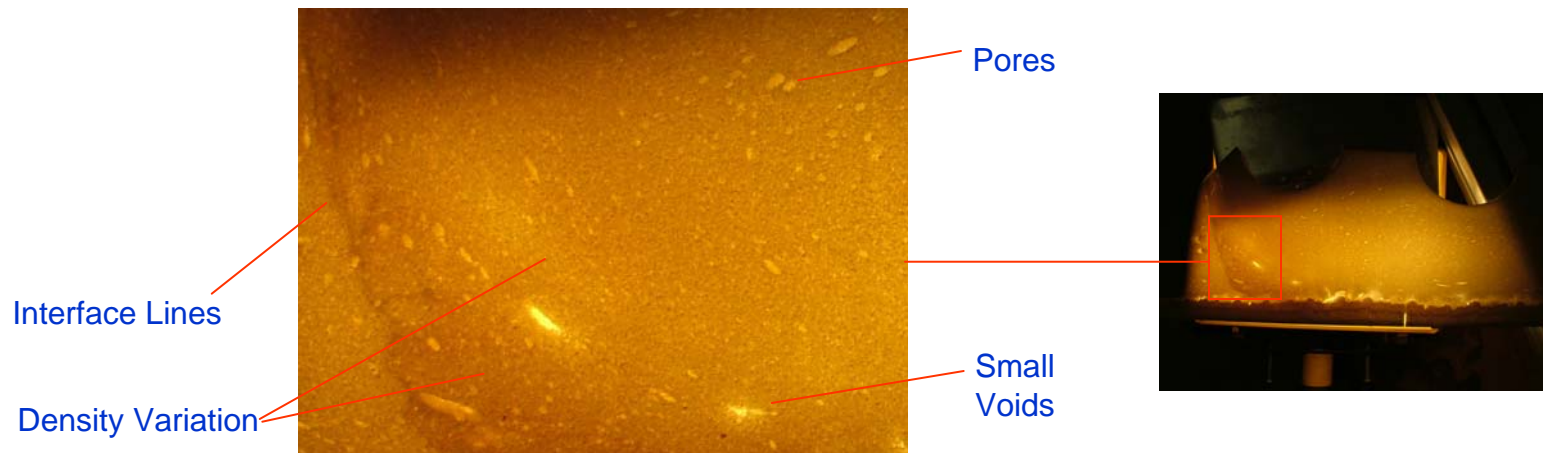


Ice frost ramps are one application that currently undergoes NDE on each External Tank.



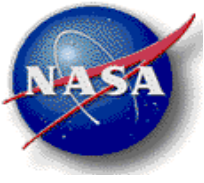
# External Fuel Tank Foam

- **NDE Difficulties in Polyurethane Foam Inspection**
  - Does not lend itself to conventional NDE methods
  - Very low density (~2.5 lbs/cu ft) so air voids do not exhibit significant density change
  - Non homogeneous material with density variations
  - Inspection must be single sided due to access restrictions
  - No history of industrial inspection of foam
- **Conventional NDE Method Assessment**
  - UT: Foam attenuates UT
  - X-ray: Requires two sided access
  - Thermography: Foam is an insulator
  - Air-Coupled, Low Freq. UT: Non-homogeneous foam structure impairs technique



**Typical Slice of ET Foam (Backlit to Emphasize Density Variations and Voids)**

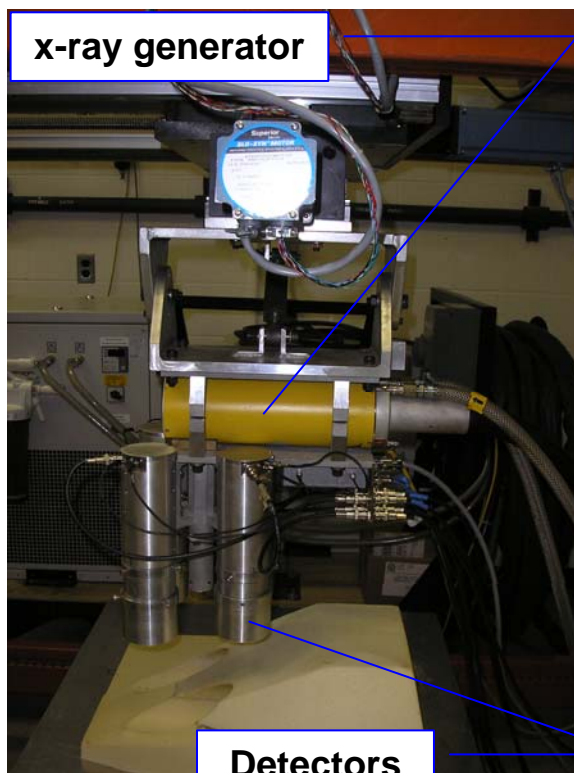
W. Ussery ASNT Digital Imaging XI



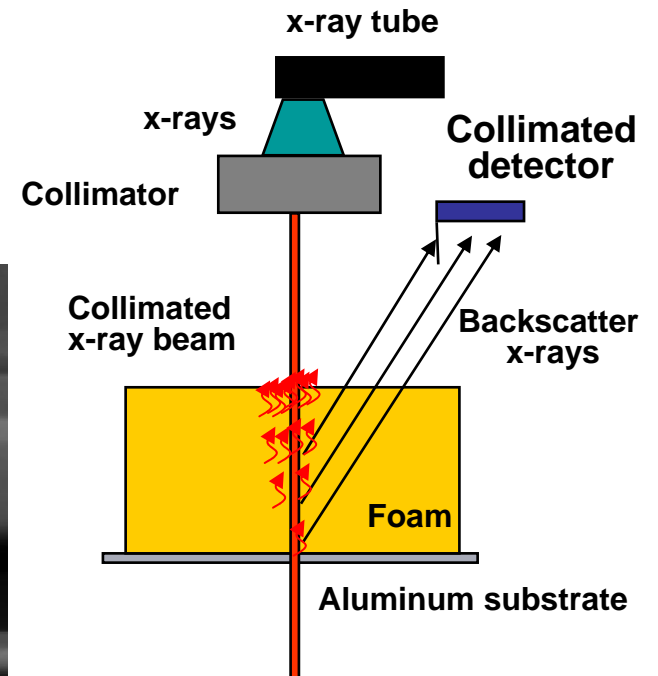
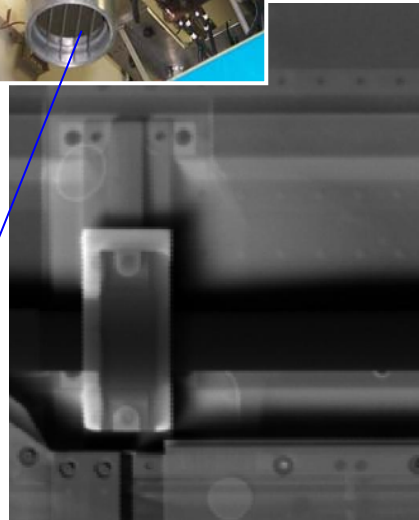
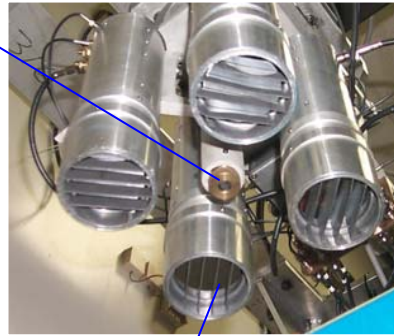
## Backscatter Radiography



- Collimated beam of x-rays (55-70 kV) interact with sample molecules
- Backscatter x-rays are emitted (Compton Scattering), possibly after multiple subsequent scattering events, and detected by NaI or YSO detectors
- Collimation provides some preferential sensitivity to selected depth
- The x-ray beam and detectors are scanned across the part to generate a 2-D presentation of the internal make-up of the foam

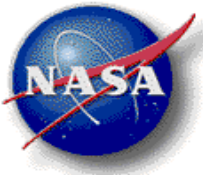


W. Ussery ASNT Digital Imaging XI

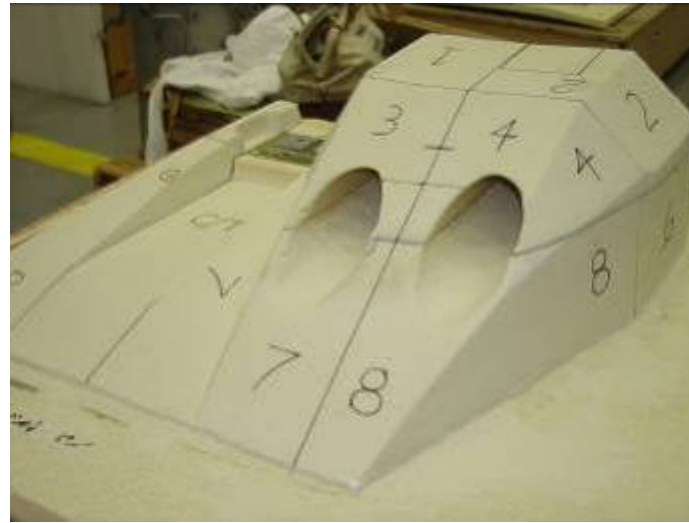
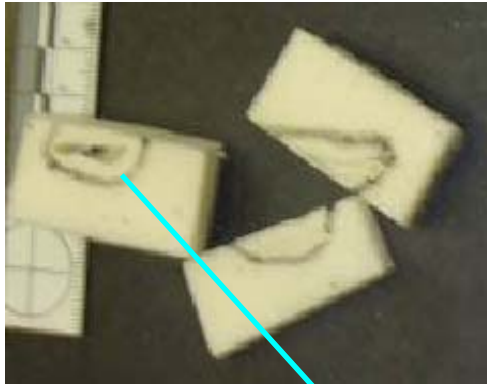


BSX Image

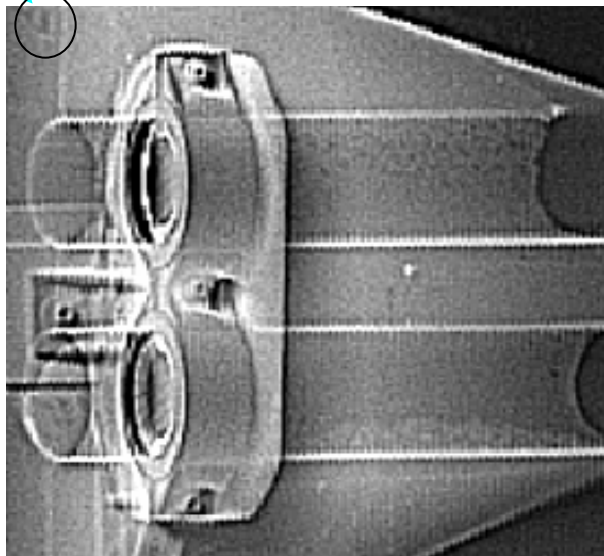
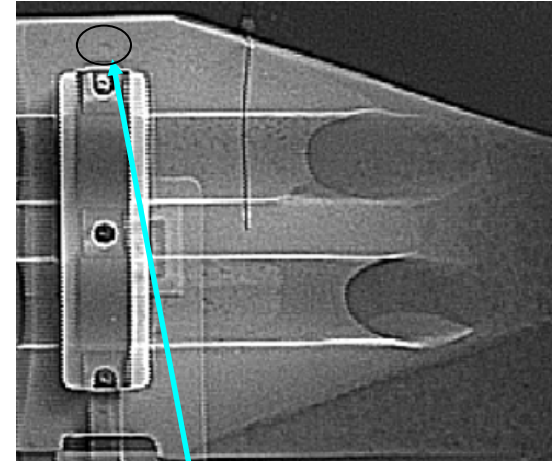


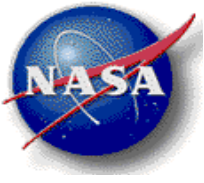


## Examples of BSX Defect Indications



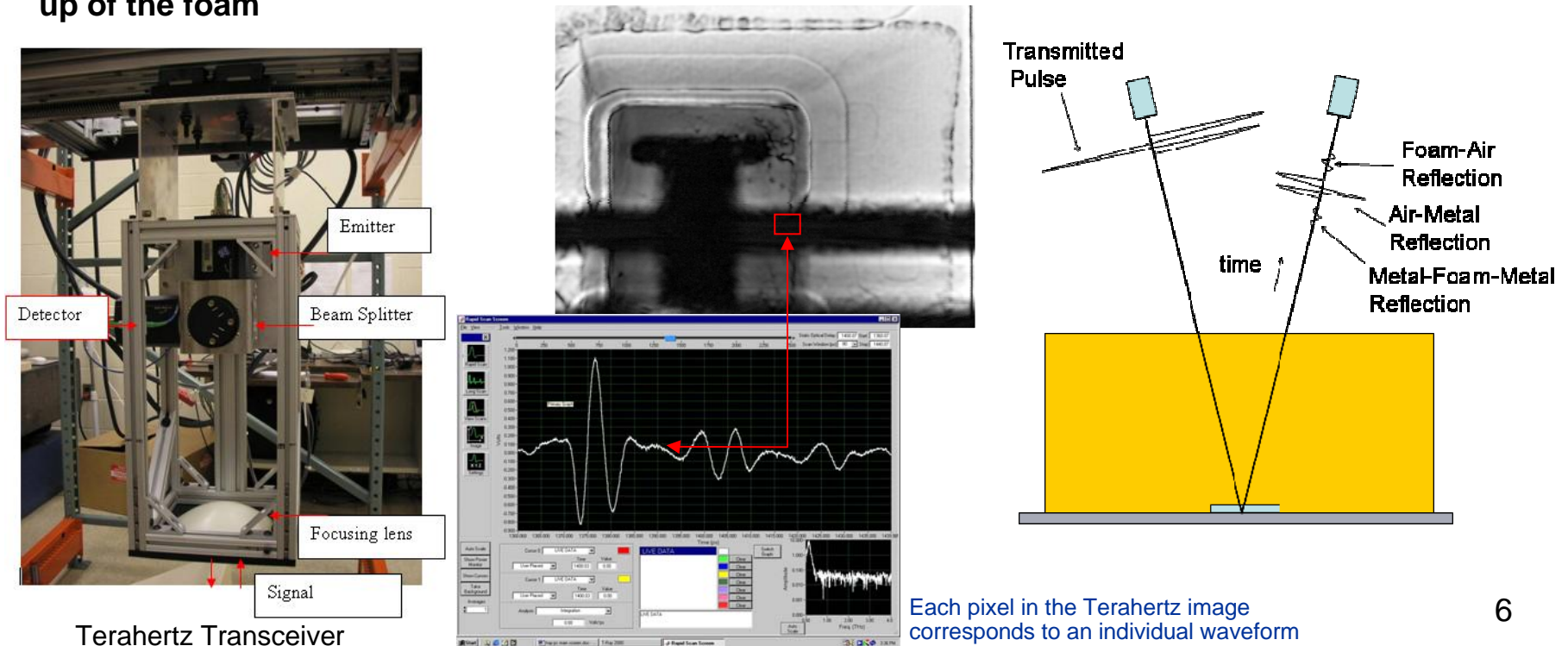
IFR test panel





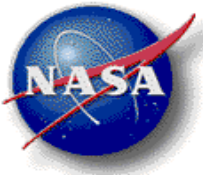
# Terahertz Imaging

- Terahertz inspection uses high frequency RF energy in the band between microwave and infrared
- Terahertz beam is transmitted through object and reflects off the aluminum substrate
- Due to foam attenuation, received pulse is approx. 0.1 to 0.3 THz (100 GHz to 300 GHz)
- Presence of defects produces changes in amplitude, phase and frequency of received beam
- Less attenuation can indicate less material such as the presence of a void but in reality there are complex refracting effects occurring in the foam, making interpretation challenging
- The terahertz beam is scanned across the part to generate a 2-D presentation of the internal make-up of the foam

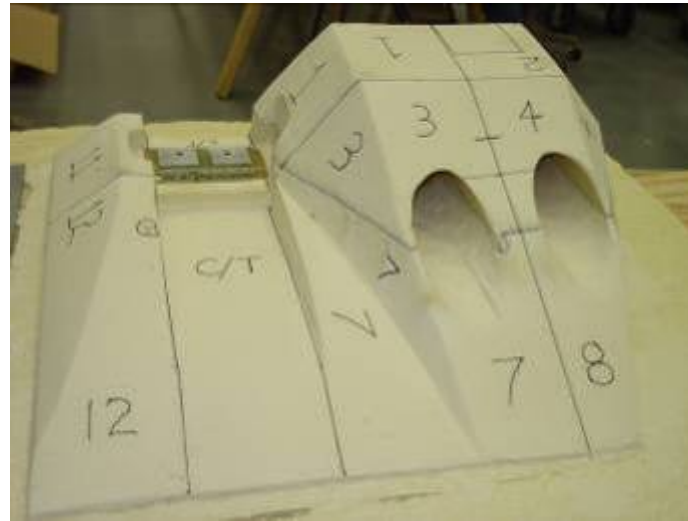
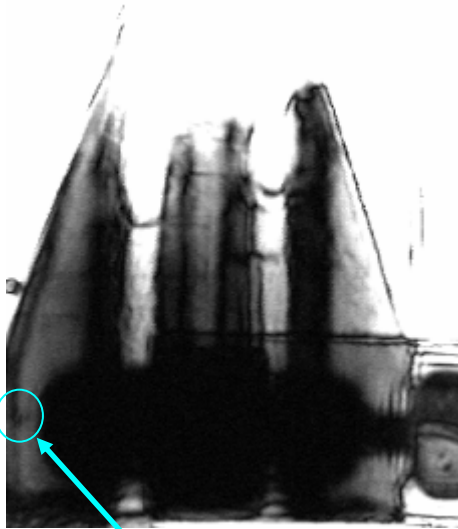


Terahertz Transceiver  
W. Ussery ASNT Digital Imaging XI

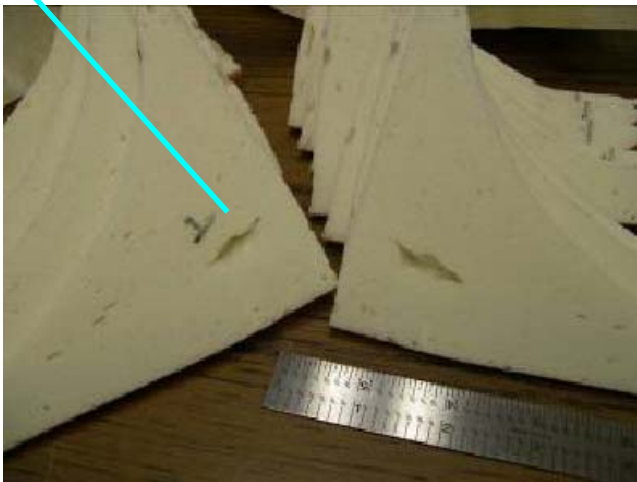
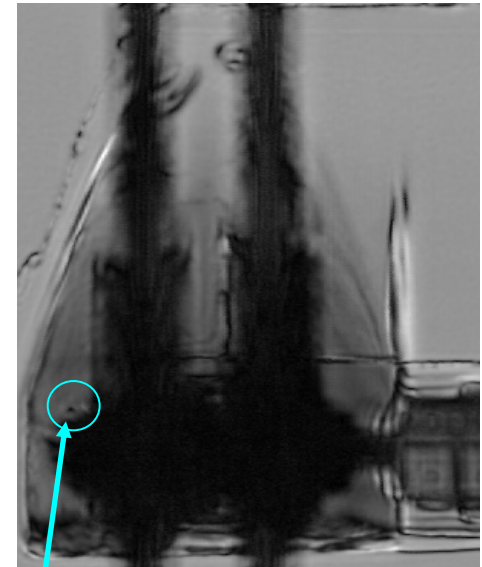
Each pixel in the Terahertz image  
corresponds to an individual waveform



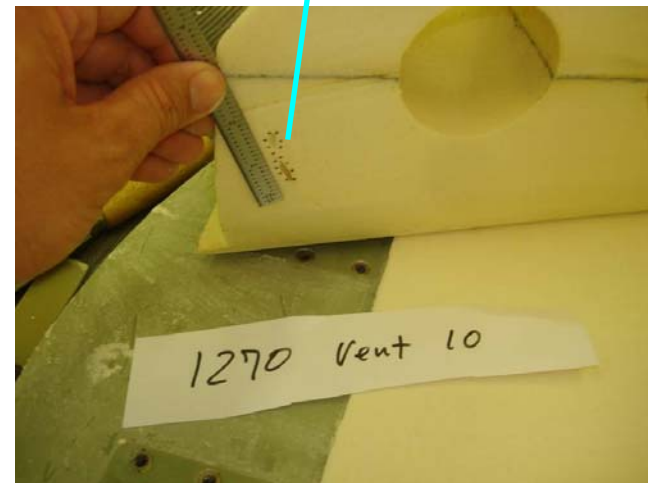
## Examples of THZ Defect Indications



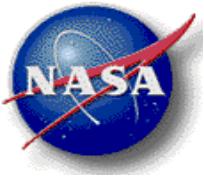
IFR test panel



W. Ussery ASNT Digital Imaging XI



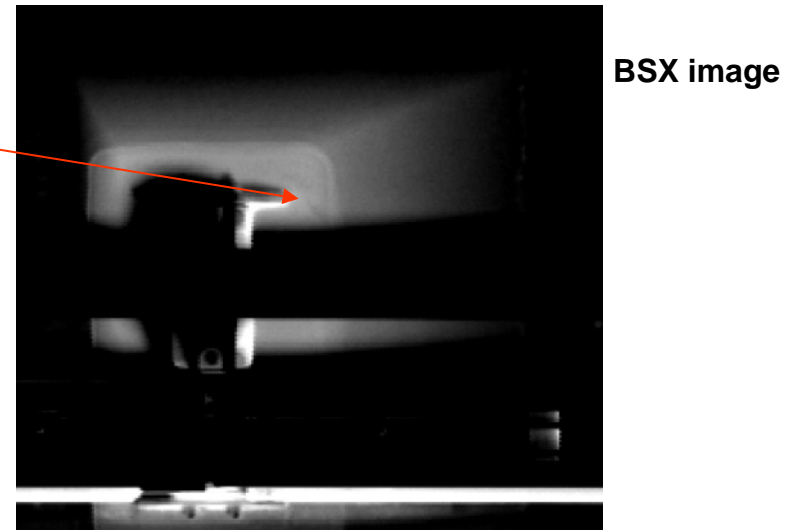
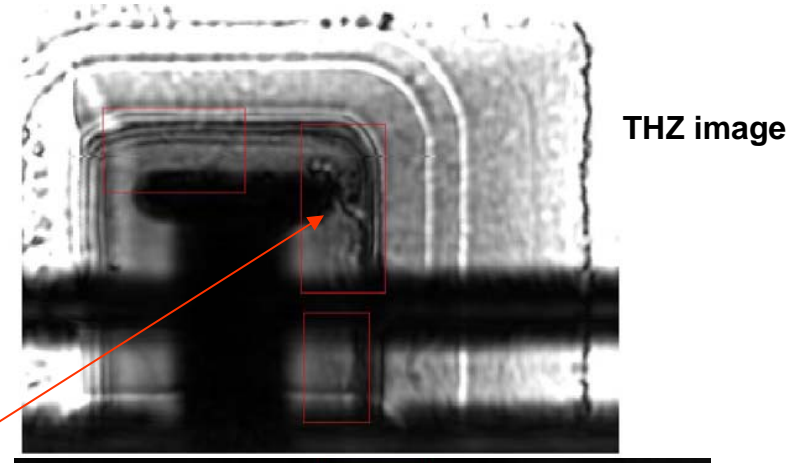




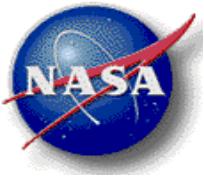
## Combined BSX/THZ Methods



- **Example 1**
  - THZ image has distinct response from void
  - BSX image has marginal response from void



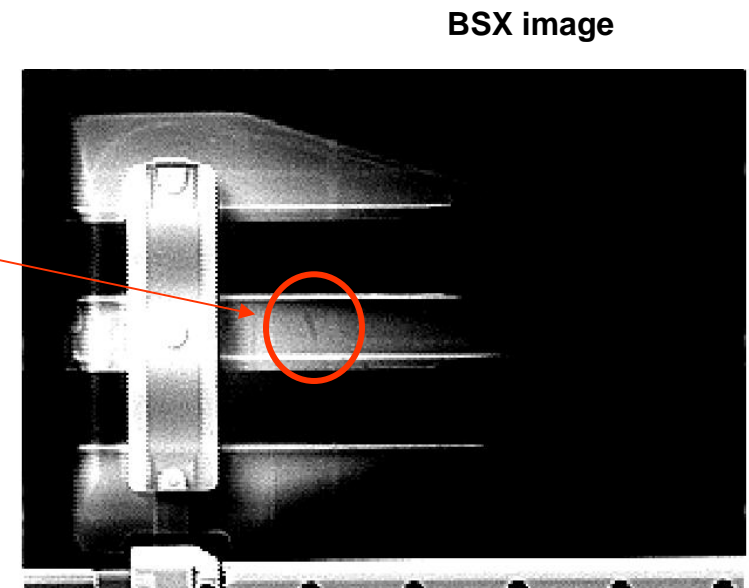
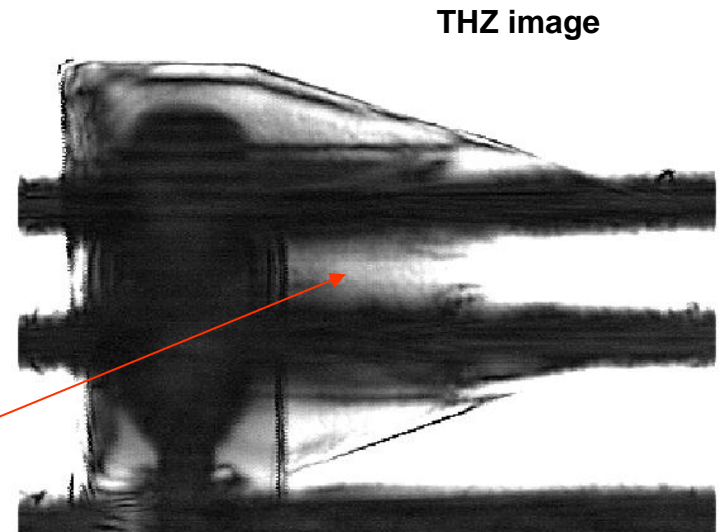
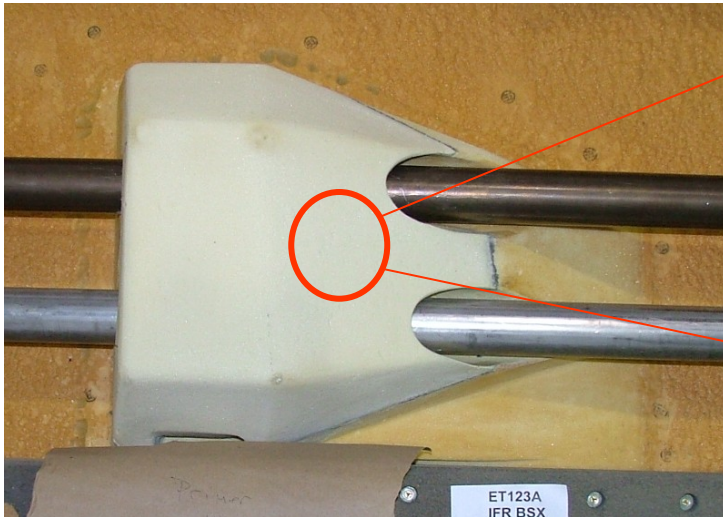


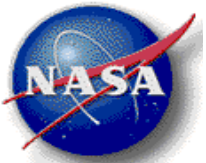


## Combined BSX/THZ Methods



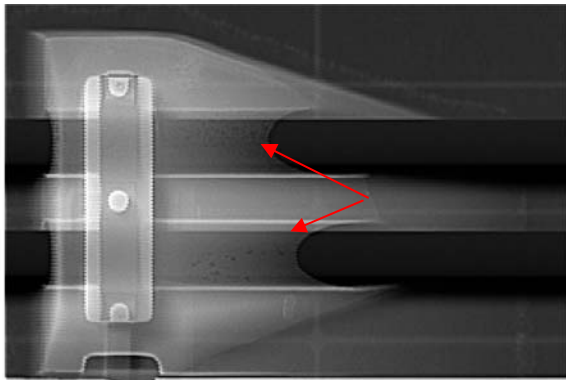
- **Example 2**
  - BSX image has distinct response from void
  - THZ image has marginal response from void



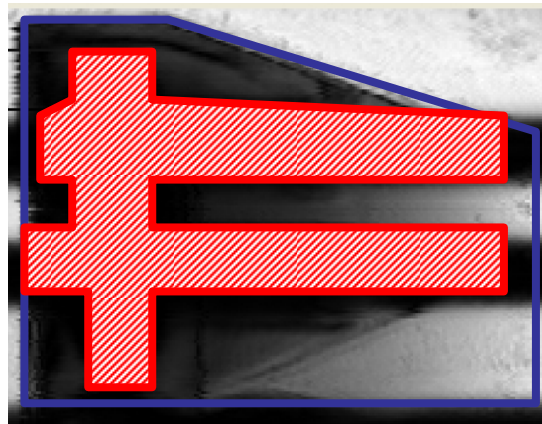


## Combined BSX/THZ Methods

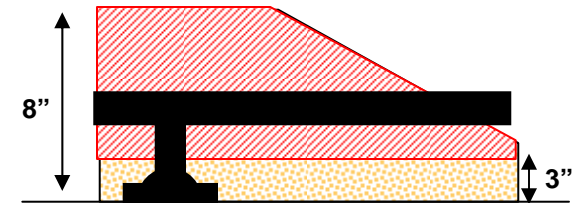
- THZ scans are limited by substrate geometry
  - THZ is 'blinded' by irregular part geometry so no THZ data can be obtained in those regions
  - THZ is most effective in the first 3" to 4" of foam adjacent to the substrate, less effective at higher elevations above the substrate
- BSX provides
  - high spatial resolution
  - most effective near the part surface



Porosity visible over press lines  
in BSX scans

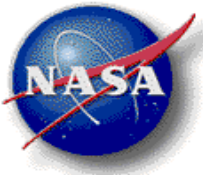


No information above irregular  
subsurface parts in THZ scans



THZ resolution degrades in  
regions above the substrate

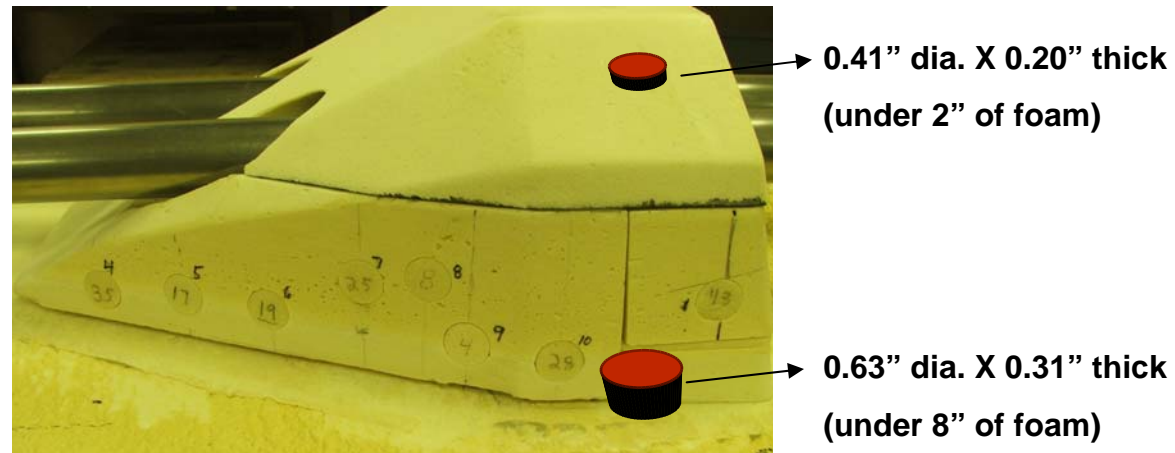
Combined BSX and THZ method provides maximum surface and substrate sensitivity and is the baseline TPS NDE inspection for volumetric defects



## Probability of Detection Results

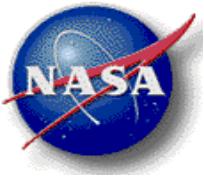


- **Detection Capability**
  - Probability of Detection Study
  - Based on combined result from both BSX and THZ inspections
  - Multivariate regression analysis
  - Samples consisted of 100 natural defects and 300 blanks
  - 90/95 detection capability established
  - Zero false calls

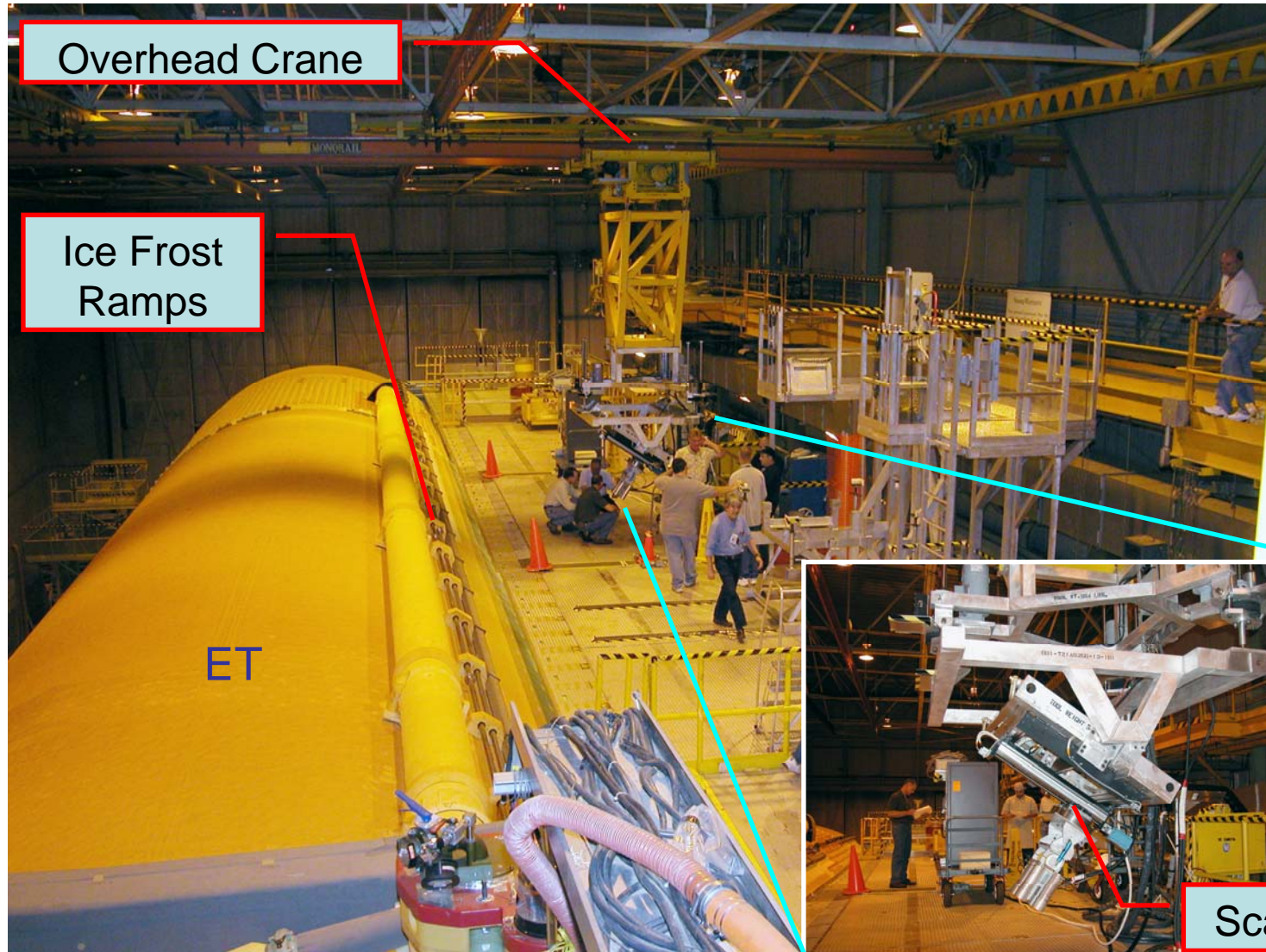


90/95 POD Results





## EXTERNAL TANK FOAM INSPECTION SYSTEM



NDE Activity in Building 420 at the Michoud Assembly Facility





## Conclusion



- Two state of the art technologies have been developed for External Fuel Tank foam inspections
- Results of POD tests have shown Backscatter Radiography and Terahertz imaging detect critical defects with no false positive issue
- These techniques are currently in use on the External Tank program as one component in the foam quality assurance program

Technique	Organization	Name	Contact Info
BSX	Univ. of Florida	Edward Dugan	352-392-1401 ext 309
BSX	Nucsafe	Dan Shedlock	865-220-5050
BSX	AS&E	Bill Baukus	978-262-8663
THZ	Lockheed Martin	Jeffery Seebo	757-864-5967
THZ	Picometrix	David Zimdars	734-864-5639
THZ	Rensselaer Univ.	X. C. Zhang	518-276-3079
BSX, THZ	NASA MSFC	James Walker	256-961-1784